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AN ANALYSIS OF FACTORS AFFECTING
THE YIELD OF WATER FROM WATERSHEDS
IN SOUTHERN CALIFORNIA.

-BY-

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AN ANALYSIS OF FACTORS AFFECTING THE
YIELD OF WATER FROM WATERSHEDS IN SOUTHERN CALIFORNIA.

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The object of this paper is to examine the problem surrounding the use of water by the chaparral forests which predominantly cover the water yielding drainages of Southern California. The question is not only how much water do chaparral or brush forests use, but how much retention water can be reduced, and how much can be carried over in slope soils from one rainy season to another. The answer to this question will not furnish the sole basis for the management of watersheds for water production; for accelerated erosion among other factors must also be considered. Yet both transpiration and evaporation makes up such large portions of precipitation supplies of water as to require careful determination as a basis for measures for maximum yield of beneficial and sustained water supply.

The treatment in this paper is confined to mountain watersheds whose yield of run-off water supplements the overhead rains in valley floors. Approximately 4 square miles of watershed are required to yield sufficient water to irrigate one square mile of the valley floor in addition to overhead rain. The problem of the contribution of rain on the valley floor to ground water supplies is not considered in this paper.

Accordingly we are here concerned with:

1. Supply, and
2. Disposition of meteoric water.

The following analysis furnishes the basis of treatment of the subject to be followed in this paper. This analysis will also serve to indicate what phases of the problem have thus far been subjected to experimental study, and the relationship of these studies to the problem as a whole.

<u>An Analysis of the Supply and Disposition of Meteoric Waters</u>

I. Supply of meteoric waters, comprises;
   1. Amount and occurrence as,
      a. Rain,
      b. Snow.
      c. Cloud drip
      d. Fog drip
      e. Intra Solum condensation.

2. Juvenile water from hot springs.

Heavy and prolonged storms furnish the principal replenishment to underground supplies under otherwise similar conditions. Thus intra solum condensation, fog drip and cloud drip as well as light rains while playing an important role in supporting the growth of vegetation, are of little or no importance in replenishment of ground water supplies.

II. The disposition of meteoric water comprises:

1. Retention, (consumptive use) being;
   a. Evaporation
      i. From soliage
      ii. From soil surfaces
      iii. From soil mass by vapor movement

   b. Transpiration.
      i. From chaparral forests on drained slopes
      ii. From subirrigated canyon bottom vegetation
   c. Water of combination, to form,
      i. Organic substances
      ii. Hydrates of oxides and silicates in rock weathering processes.
   d. Abysmal seepages.

2. Run-off, being;
   a. Ground water drainage, (springs)
   b. Storm flow, combining;
      i. Shallow seepage or the discharge of wet weather springs
      ii. Superficial or surficial run-off which represents the unabsorbed portion of rainfall or melting snow. Surficial run-off has been a factor subjected to detailed experimental studies.

3. Deep seepage, or deep penetration which escapes by slow percolation through rock masses without following drainage channels.

Discussion of the Analysis

I. Supply of meteoric waters

The supply of meteoric waters in southern California is derived chiefly from Pacific Ocean Clyconic storms invading the land area. It occurs predominantly as rain and snow. The total supply of precipitation has been determined adequately in only a few instances. Very few of our watersheds are equipped with instruments to measure the intensities as well as amounts of rain to a degree satisfactory

for calculating the total catch of watersheds. While the measurement of rain presents certain problems in accuracy, the measurement of snow involves the dealing with still larger errors. A first requisite in studies of the disposition of meteoric waters is a measurement of precipitation supplies within a determinable degree of accuracy.

The following criterion of adequacy of rain gages is suggested. Rain gages will be considered sufficient in number and correctly located when the values of catches by isohyetal zones show the same relationship to a frequency distribution as the catches of all individual rain gages employed on the catchment area. (also see Whitney 1929).

But rain and snow do not comprise the sole source of meteoric waters. We know thus far little about fog drip, cloud drip and intra solum condensation. Fog drip is common in the fog belt of California and during the rainless season brings to the ground observable quantities of water. The importance of this source is not yet fully known. Cloud drip is common above the cloud line over the state. Cloud drip has been recognized by many students of water supplies, (Schubert 1917 Perez 1925, Brooks 1928). Descombes (1918-22-23) was obliged to consider cloud drip or "Occult condensation" in addition to measured precipitation to account for total run-off in watershed studies in the Pyrenees. The comparative studies of Dr. W. P. Hoge of the Mt. Wilson Observatory furnish rather startling results, (1919). Gages beneath trees received as much as 265 per cent of the catch in the open. These results can be accepted only as an indication of a phenomenon, which is common in our mountains, and which requires further study. Intra-solum condensation is the direct condensation within the soil of moisture from the air. Lebedeff (1928) was experimentally determined that such condensation takes place under certain conditions. It is probable, however, that intra-solum condensation plays an insignificant part in the yield of watersheds in streamflow.

Certain important conditions determine the effectiveness of the supply of meteoric waters for yield in irrigation water. Gilman (1930) and Blaney (1929) have called attention to the necessity of recognizing the influence of intensity and distribution of rains on yield and penetration. The total amount of precipitation is no satisfactory measure of the effectiveness of the season's fall. The more important of these conditions are:

1. Distribution.
2. Intensities
3. Duration and amount by storms
4. Weather conditions between storms
5. Time of fall in relation to growing season.

$$P = R \quad E \quad S_t$$

where S_t = temporary underground storage.

Storm flow, on the other hand, represents the flow in excess of ground water drainage responsive to storms of rain and snow. Storm flow requires further division into:

a. Shallow seepage, or the discharge of wet weather springs, and
b. Superficial run-off or surficial run-off which represents the unabsorbed portion of rainfall or melting snow.

The significance of surficial run-off as represented in a series of studies of factors influencing surficial run-off has been considered elsewhere by the writer. (1930)

Retention or consumptive use

The remaining factor to be considered in the disposition of meteoric waters is the retention of water by the catchment area. It is also designated "consumptive use". Retention or consumptive use may be further divided into

i. Evaporation
ii. Transpiration
iii. Water of combination
iv. Abysmal seepage

Abysmal seepage, being that which penetrates to great depths in consolidated rock, may be assumed to have saturated the rock in past geologic time. It could be increased by uplift of the land surface. Even geologically rapid rates of uplift are assumed to render such amounts of water of little significance in water conservation schemes in southern California.

Water of combination is withdrawn in the formation of or organic and inorganic compounds. Water combined in organic substances is returned to the atmosphere as vapor as they decompose. This quantity is small and represents approximately 0.1 per cent of transpiration of plants, (Livingston & Shreve 1921). Inorganic compounds include hydrated oxides and silicates, resulting from the weathering of rock. This withdrawal is relatively permanent, but is of small moment in water supplies.

Transpiration

Transpiration includes water taken up by roots and given off from the aerial parts of plants. The principal portion of transpiration is given off through leaves. The

Factors which determine the effectiveness of precipitation have not thus far received adequate attention. Such determination procede in importance the modifying influence of other factors. Methods of experimentation which have recently been employed to measure the effectiveness of precipitation will be considered below the heading of evaporation and transpiration.

II. Disposition of meteoric waters

The disposition of the aggregate supply of meteoric water is even more complex. Precipitation becomes:

1. Retention (consumptive use)
2. Run-off
3. Deep seepage, or deep penetration

Deep seepage refers to water percolating through rock masses into valley basins without following surface drainage channels. Geological structure of country rock primarily determines the amounts of deep penetration. It is probable, however, that the rapid lowering of water tables in the valley fill basins of southern California has increased the amounts of deep penetration over those of the pre-agricultural perios in this region. These amounts of water are indeterminate, but may be small in comparison with the discharges of drainage channels.

Run-off, as has been indicated in the analysis, includes the surface streamflow and subsurface flow in detrital filled drainage channels. This fraction has been divided into

1. Ground water drainage, and
2. Storm flow

Ground water drainage is the aggregate flow from springs. It lags behind rainfall in a manner characteristic of each watershed. The studies of Shuman (1929) have correctly indicated this. The lag in flow involves temporary underground storage which will interfere with the accuracy in such an equation as

$$P = R \quad E$$

Where $P =$ Precipitation
$R =$ Run-off
$E =$ Evaporation opportunity, or consumptive use or retention

When deep seepage is ignored, the more correct expression is:

stems as well as dead plants give off small quantities of moisture to the atmosphere. (Maximov 1929).

Asfar as is known no studies of transpiration have been made which serve to indicate the transpiration losses from chaparral forests by area in SouthernCalifornia. Data including the combined amount of transpiration and evaporation, do not permit the segregation into component values without experimental study.

The following general feature of the problem have received consideration in the present undertaking by the California Forest Experiment Station to study transpiration losses experimentally. It is essential that all phases of the problem be considered in conducting experimental determinations.

The first features to be considered is the relation of the rainy period to the growing season. Winter rains and dry summers simplify this problem in one particular. The degree of arrested growth in winter varies with altitude and latitude. In the valleys of southern California the growth of evergreen plants is much retarded, or completely stopped. The transpiration losses during winter are much less than during the favorable growing temperatures of summer. At increasing altitudes up canyons and mountain slopes transpiration decreases to a minimum at snow line. Likewise the length of the growing season varies in length with altitude, being longest, of course, at valley elevations.

Growing and rainy seasons are coincident to a varying extent. Overlaps of favorable growing temperatures above a diurnal average of 40°F. (Livingston and Shreve 1921), and rainy seasons vary also with altitude. It is necessary to determine the importance of transpiration during the overlap periods for the entire range in altitude.

The second important feature of the problem in Southern California is the recognition of two major types of vegetation included within the watersheds of the region. They are, (1) the vegetation confined to drained slopes, and (2) the canyon bottom or stream side vegetation which enjoys sub-irrigation throughout most of the entire period of favorable growing temperatures. The sharp division between these two types is discernable from vantage points on ridges. Type maps now being made under the supervision of A. E. Wieslander of the California Forest Experiment Station, clearly shows the type boundaries and the comparative area covered by each type. These distinctions become less conspicuous with increase in altitude above the cloud line.

These two types of vegetation are believed to have widely different quantities of water at their disposal. On the drained slopes the water holding capacity or field capacity of the soil less the moisture at the wilting point

represents all the moisture available to vegetation after the last rain in spring. After the chaparral forest has extracted the easily available moisture it must survive on very small amounts of moisture throughout the remainder of long seasons favorable to growth. Pearson (1926) found that pine (Pinus ponderosa) and Rocky Mountain Douglas fir (Pseudotsuga taxifolia) rapidly consume available water, but are capable of surviving for long periods of time on very small quantities of moisture. It seems probable that chaparral vegetation is required to do this. Its dwarfed form is doubtless a response to the limiting factor of moisture.

On the contrary, the vegetation in canyon bottoms has all the water it can use at its disposal throughout the summer. The species of the vegetation are mesophytic and are unmistakable indicators of this condition. They are willows, alders, sycamores, grapevines, all of which transpire great quantities of water which Rowe (1924) found at the mouth of White Water River to approximate the evaporation from a free water surface, a total of about 8 acre feet per year.

These considerations have an important bearing on explanations of observed increased flow in streams and the opening of small springs at the lower ends of willow flats following forest fires. It is, for this reason, probable that such increases in flow come from a reduction in transpiration losses from the subirrigated canyon bottom vegetation rather from the chaparral vegetation on drained slopes. In fact, it is impossible to see how a fire would cause the slope soils to give up any of their capillary water to underground flow. On the contrary forest fires can be expected to increase evaporation from the soil. Conspicuous soil slides following fires are indicative of a powder dry condition of soil which fire has produced.

More significant still is a consideration of the possibility of carrying field capacity water in drained soil for one rainy season to another. To increase the yield of water from drained slopes it is necessary to hold over such increases in the soil to the succeeding rainy season, where it is effective in increasing gravity flow. Summer fires are followed by the rainy season. Under light intensities of rain erosion may not be conspicuous, but under heavy intensities accelerated erosion is a common associated phenomenon with burned watersheds. During the following spring burns are reclothed with vegetation in varying degrees. We need to know more accurately the density and kind of regrowth. Some types of growth such as the chamise (Adenostoma fasciculatum)and oak (Quercus dumosa) sprout vigorously following fires. It is common for a luxuriant growth of herbaceous vegetation to follow fires to be gradually succeeded within about 5 years with the woody

chaparral species which formed the original cover. The succession of seeded vegetation is slower on large burns, due in all probability to lack of disseminated plant seed.

The regrowth on burns in the first season, as well as in succeeding years, has before it a long season with temperatures favorable for growth. Temperature is not a limiting factor. The regrowth can be expected, therefore, to grow as long as it has moisture available in the soil. In the case of sprouting vegetation the reach of the roots doubtless is identical with that of the plants before a forest fire. In the case of herbaceous vegetation and new woody plants from seed the roots may or may not reach the depths of the former cover. Yet it seems probable that growth would continue until all available moisture within the root zone was consumed. Thus the height of vegetation is not supposed to be an index of the amount of transpiration on drained slopes. In fact it appears probable that the sprouting plants transpire more energetically and more water if it be available than the mature plants. Experimental determinations are needed to check this hypothesis, which is formulated on an analysis of the factors involved in the problem.

In order, therefore, to increase the yield of water from the drained slopes, it would seem to be necessary to kill the vegetation permanently. Instances exist in California where this has been done by smelter fumes. The Kennett area north of Redding is a good example. It is more than probable that the yield in run-off has been increased in this area over the pre-smelter days. This interesting area, incidentally, offers an unparalleled opportunity to test experimentally the effect of the total destruction of the mantle of vegetation on the yield of water from watersheds. Certainly the evidence is not sufficient to advocate the employment of smelter fumes to increase water supply with the attendant acceleration of erosion, increased turbulency of stream discharge and fatal consequences, to agriculture.

It follows that a very fruitful source for increased yield of water is the reduction of transpiration from summer growing canyon bottom vegetation. To cut it or kill it by fire would be both unsatisfactory and would at best net only temporary increased. This method which has been employed in a number of instances, of robbing this vegetation of the drainage flow by collecting and piping it out of the canyon offers the greatest promise. This method is suggested as a certain means of increasing the yield of water from mountain watersheds.

<u>Evaporation.</u>

Evaporation may be the most important factor in retention or consumptive use in Southern California, When

considered as direct losses from wetted surface it comprises:

1. Interception by vegetation and its litter
2. Interception by soils.

The ratio of evaporation to transpiration will depend on the characteristice of precipitation. If all rain in southern California should occur as 0.5 inch storms one week apart evaporation would account for practically the total supply of meteoric waters. The manner of occurrence of precipitation is doubtless of more importance in determining the supply of underground water than the presence of absence of vegetation on a watershed. Any determinations of the yield of streamflow from rainfall, which does not take into account this feature of the problem not only is incomplete but may actually mislead.

Accordingly determinations of the factors controlling the effectiveness of rainfall are of more importance within certain limits than those of total amount. The studies of the interception of vegetation by Engler (1919) Munns (1921), Bates and Henry (1928), and Hirata (1929) all indicate that light rains scarcely reach the ground. Only the heavier falls replenish soil moisture.

Exposed bare soils function in a way similar to that of vegetation. The soil layer of the most active capillary movement including a depth of approximately 8 inches acts in a way analogous to the interception of vegetation. Rain which do not wet below this depth may be lost by evaporation if a few days of clear weather follow storms.

Thus a comparison of the evaporation losses by a mantle of vegetation and by bare soil involves a weighing of relative values. Engler (1919) found as had Ebermayer (1876) and Henri (1908) that whereas the mantle of vegetation reduces the contribution of water to the soil, yet it reduced the evaporation of such supplies that were absorbed by the soil in comparison with the evaporation losses from bare soils.

This phase of the problem requires careful, experimentation. Experimental studies were undertaken by the California Forest Experiment Station in 1929 to answer some of the questions which have been raised here. The principal objective is to discover the portion of a season's precipitation by amounts and intensities of storms, which passes through vegetation, litter layers, and layers of soil of different depths up to 3 feet. Instruments are designed to measure the following factors:

1. Interception of rain by vegetation.
2. Amounts of rain which pass through
   (a) Litter layers
   (b) Litter and soils of different depths
   (c) Bare soil of different depths
3. Water losses from soil columns 3 feet deep by evaporation, and by transpiration.

In conjunction with this instrumentation soil moisture sampling is being conducted in a preliminary way at 3 sampling areas. A general systematic attack on the sampling of soil within and without vegetation throughout the year is planned for this and the following year,

Summary

The supply and disposition of meteoric waters have been analyzed into their several factors. Studies of specific factors have been suggested and their relation and significance to the problem as a whole have been indicated. Points where additional experimental information is needed are set forth. A series of coordinated studies are still necessary to answer adequately what role the chaparral forests play in water economy and conservation in southern California. These as well as other considerations are fundamental in selecting measures for managing mountain areas for the yield of the maximum sustained beneficial water with the minimum of damages from erosion, and other consequences.

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